
Sensors Expo
05
Smart Sensors' Role in Integrated System Health Management
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Introduction

- Access to space has become very competitive
  - Europe, Japan and China have driven down the cost-per-pound of payload to almost a third from 1990 to 2000
  - Cost has leveled in recent years to around $12,000/lb
- One of NASA's goals is to reduce this cost by a factor of 10 or more by fostering new technologies development
  - Affordable space exploration is a must----and commercial involvement is key
- A technology that will help lower costs is the "Integrated System Health Management (ISHM)"
  - Will help reduce the operating, processing and maintenance costs in flight vehicles and ground support systems.

Integrated System Health Management (ISHM)

- ISHM automatically and autonomously acquires information from sensors and actuators and processes that information using embedded knowledge.

- ISHM establishes the health of the system based on the acquired information and its prior knowledge.

- Ultimately, ISHM systems shall perform failure prediction and remediation before actual failures occur, preventing costly consequences.

Current Gaps in ISHM

- Algorithms and Models
  - Health Monitoring, Prediction and Diagnostics
    - Degradation, Failure, Remaining Life
  - Autonomous Operation
    - Including auto-calibration and reduced maintenance cycles
  - Ability to Certify
- Tools
  - Design tools for optimized ISHM systems and sensor networks
  - Understand and capture decisions currently made by people

Current Gaps in ISHM

- Standardized Interfaces and Protocols
  - Simpler to interface separate systems
  - Better integration of information among separate systems (e.g. Vehicle ISHM, Command and Control, Ground Support Equipment, Logistics, etc…)

- Advanced Architectures
  - Reconfigurable
  - Upgradeable
  - Support Multiple Configurations of Vehicles or Equipment

Current Gaps in ISHM

- Capacity to transfer larger amounts of *information*
  - Higher bandwidth
  - Bandwidth "on-demand"
  - Intelligent processing of data

- Increased Certainty/Reliability
  - High-quality data is a central goal of ISHM. Data sources, sensors and their associated data acquisition systems constitute the foundation of the system.

Smart Sensors and ISHM

- Smart Sensors
  - A smart sensing architecture supports the acquisition of reliable, high quality data to be used by the ISHM

- Establish/standardize a thorough definition of Smart sensors
  - Architecture, Embedded diagnostic agents and communication protocols

Definition of Smart Sensor

- IEEE definition of a Smart Transducer
  - *IEEE1451.1: 3.134 Smart Transducer: "A transducer that provides functions over and above that necessary for generating a correct representation of a sensed or controlled physical quantity. This functionality typically simplifies the integration of the transducer into applications in a networked environment."*

- IEEE Detailed Architecture for Smart Transducers
  - It is specially detailed describing the communication mechanisms to be used by smart transducers. The main goal of IEEE 1451 is to develop an architecture that is network and vendor independent with a common transducer interface.

Characteristics of Smart Sensor

- Self-identification (Configuration Control)
- Embedded intelligence
  - Data digitization and conversion
  - Time stamping and data synchronization
  - Complex signal processing (trending, averaging, etc)
  - Data storage
- Self-health assessment
  - Auto-calibration capability
  - Self-reconfiguration capability
- Health Management capability
  - Proposed Health Electronic Data Sheets (HEDS) approach
  - "health parameters are calculated, monitored and stored in the Smart Sensors to aid in the determination of the sensor's health"

Smart Sensors - Benefits

- Assure Data Validity
  - Measurement self-health capability
    - Embedded calibration capability
    - Embedded failure detection and correction capabilities
- Assure Data Availability
  - Networked sensor system
    - Provide alternate path to measurement
  - Embedded data storage capability
- Increase Reliability
  - Reduced calibration cycles
  - Self-reconfiguration capability
- Information versus data
  - Data trending, bandwidth, etc.

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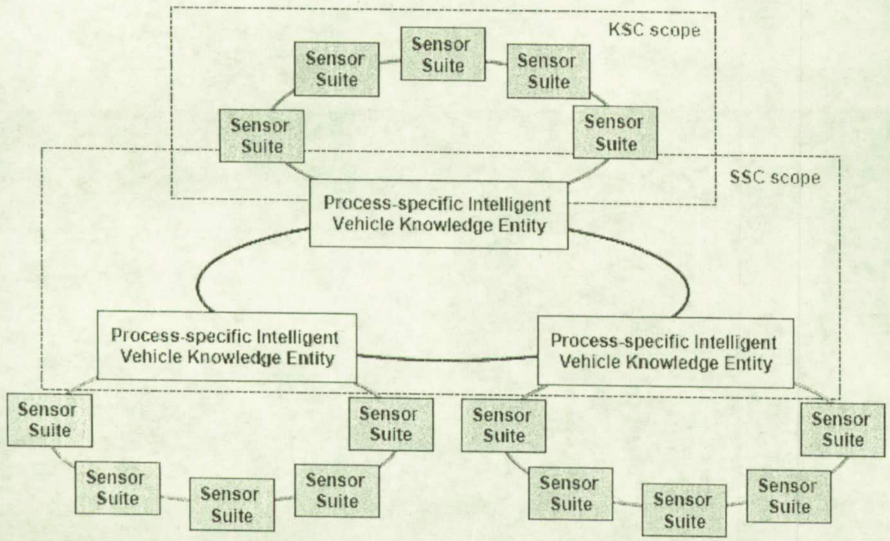
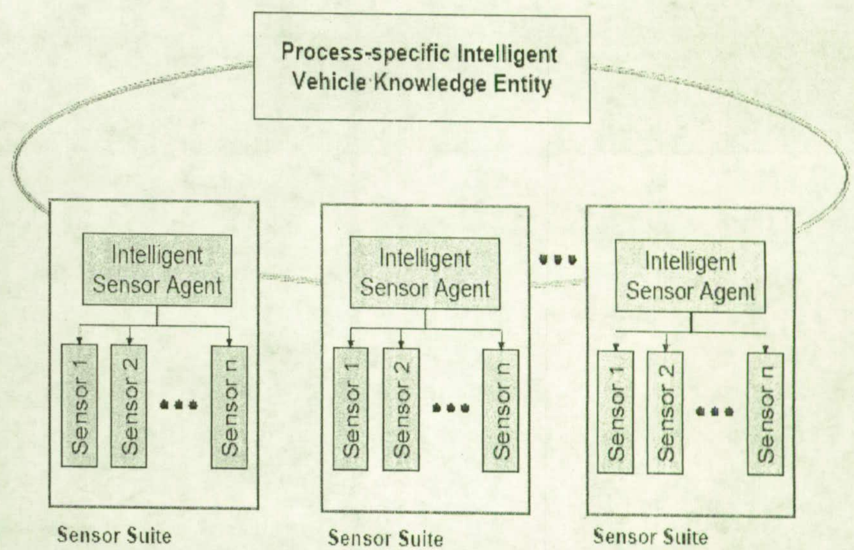
KSC Smart Sensor Architecture

Overall System Architecture



Sub System Architecture



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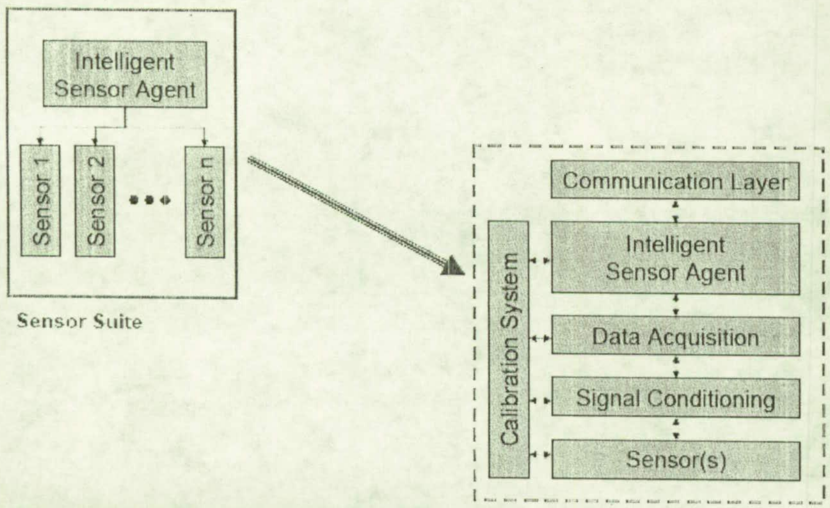
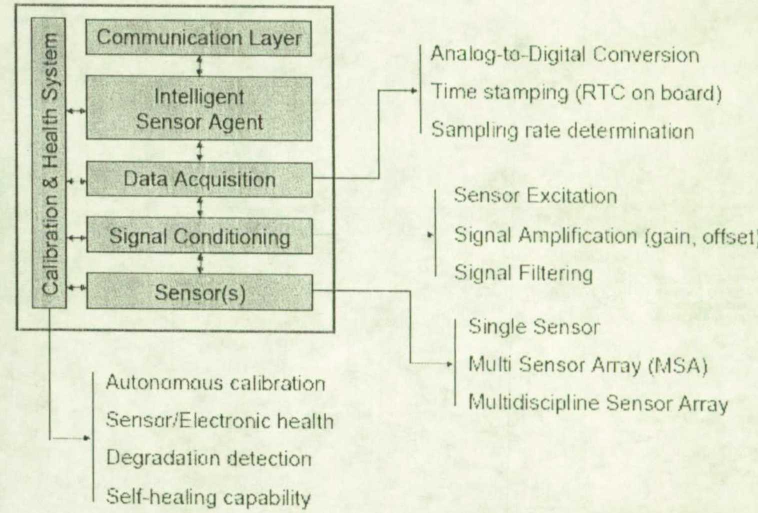
KSC Smart Sensor Architecture

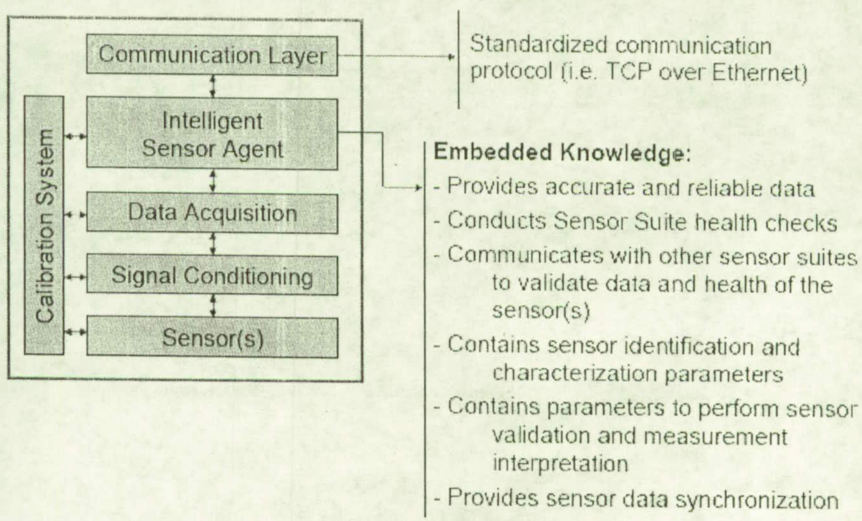
Sensor Suite Architecture



Sensor Suite Architecture



Sensor Suite Architecture



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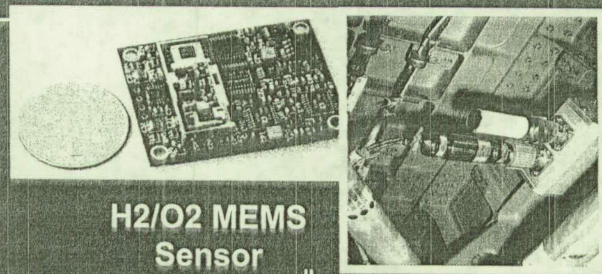
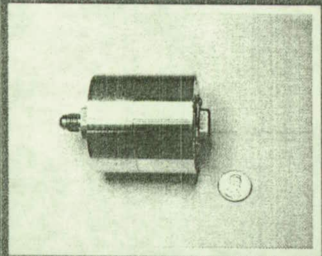
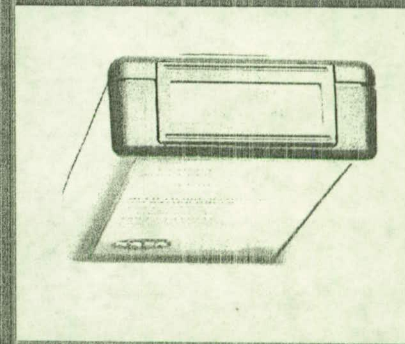


H2/O2 MEMS
Sensor

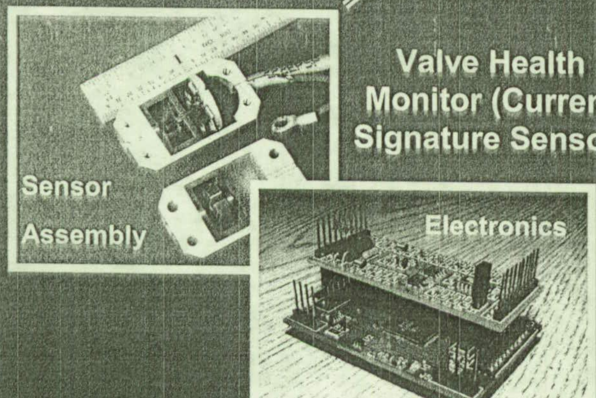


Multi-Sensor
Array Pressure
Transducer

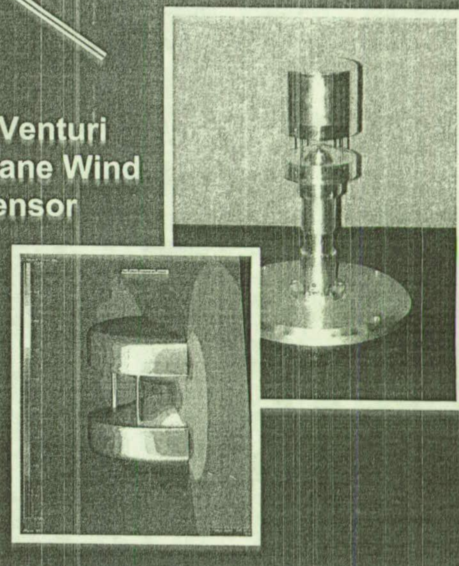


Cabin Pressure
Monitoring
System

SMART SENSORS



Valve Health
Monitor (Current
Signature Sensor)



3-D Venturi
Hurricane Wind
Sensor

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Multi-Sensor Array (MSA) Transducer

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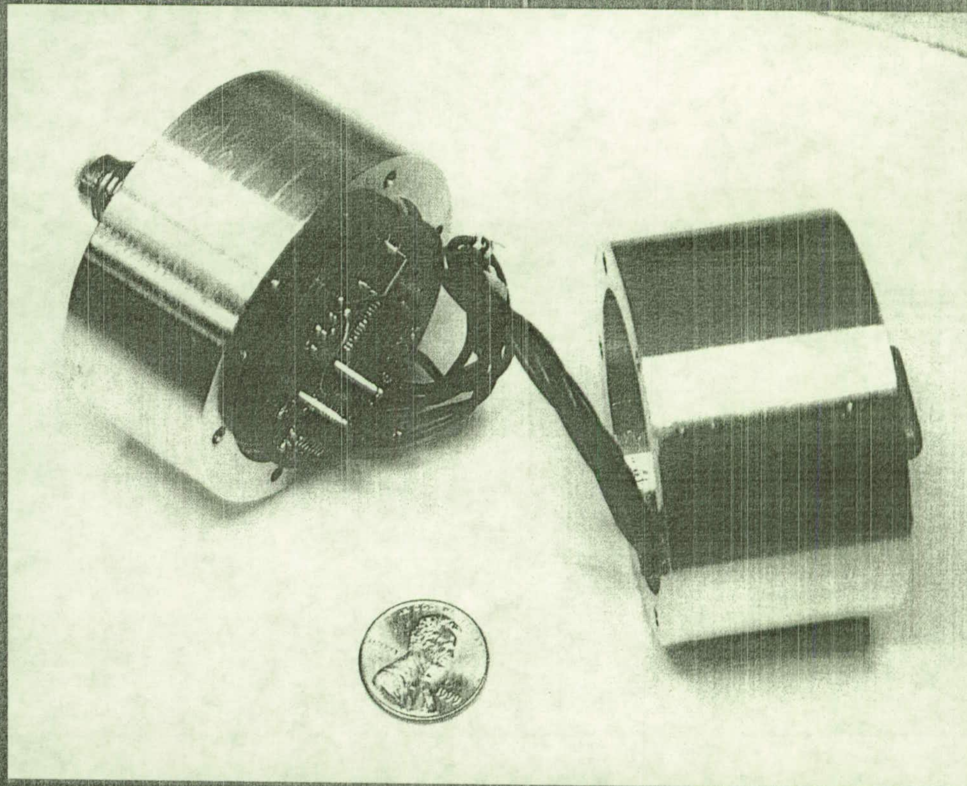

Objective

To develop a fault-tolerant transducer architecture to increase at least 3x present calibration cycle times and increase measurement reliability.

Approach

Array of MEMS sensors and KSC-developed software algorithms to achieve objectives. Electronics also provides autonomous self-health checks.

Status

- Reliability studies were completed on 8-pressure sensors array.
- KSC-developed algorithms have been developed and tested.
- Sensor failure simulation was performed to validate software algorithms.
- Ruggedized field prototype (8-element array) was developed and tested.
- Patent was granted to KSC and Licensing was issued to TABER industries for commercialization purposes

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Advanced Mini Smart Leak Sensor

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This is a joint effort Between GRC, KSC, MSFC, and MAKEL Engineering.

KSC Objectives

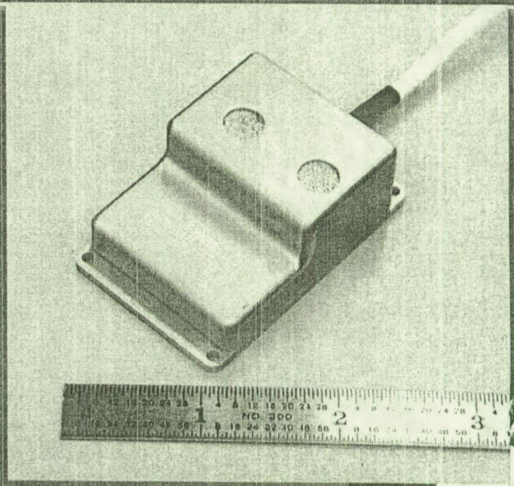
KSC provides technical expertise in the transition of sensors developed by GRC into units suitable for aerospace application. KSC is performing all the necessary environmental testing required by flight vehicles, as well as materials compatibility analysis. Furthermore, KSC provides technical feedback to GRC to aid in the achievement of the final product.

Status

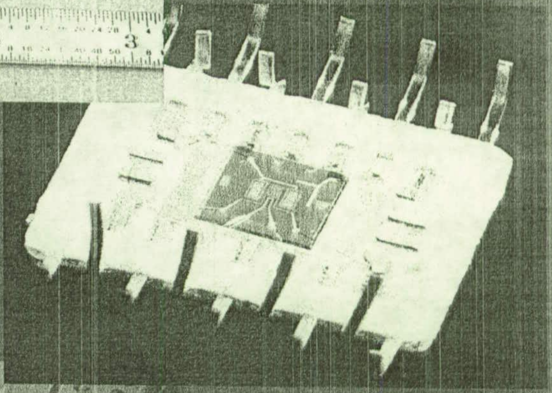
- Third set of prototypes are being tested at the present time.

Future Objectives

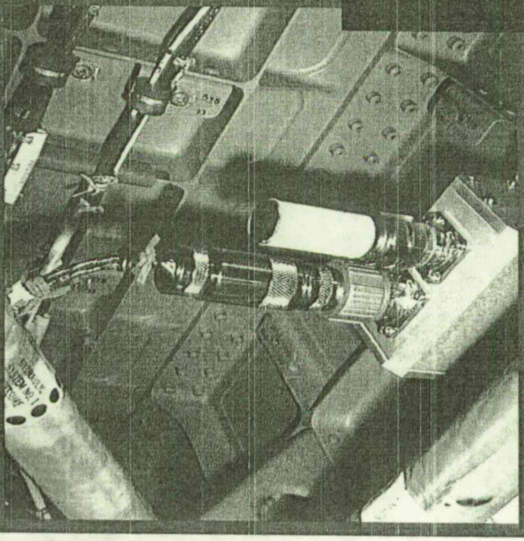
- Wireless Hydrogen Sensor Network (wireless sensor prototype presently under test)



Prototype Hydrogen/Oxygen Sensor System with Electronics



Micro-fabricated Hydrogen Sensor



Hydrogen Sensors on Space Shuttle

Photos provided by Dr. Gary Hunter (GRC)

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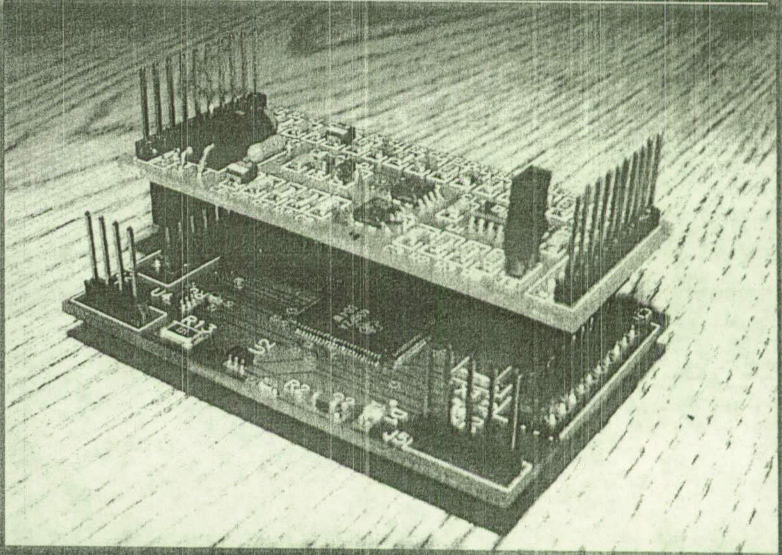
Valve Health Monitor

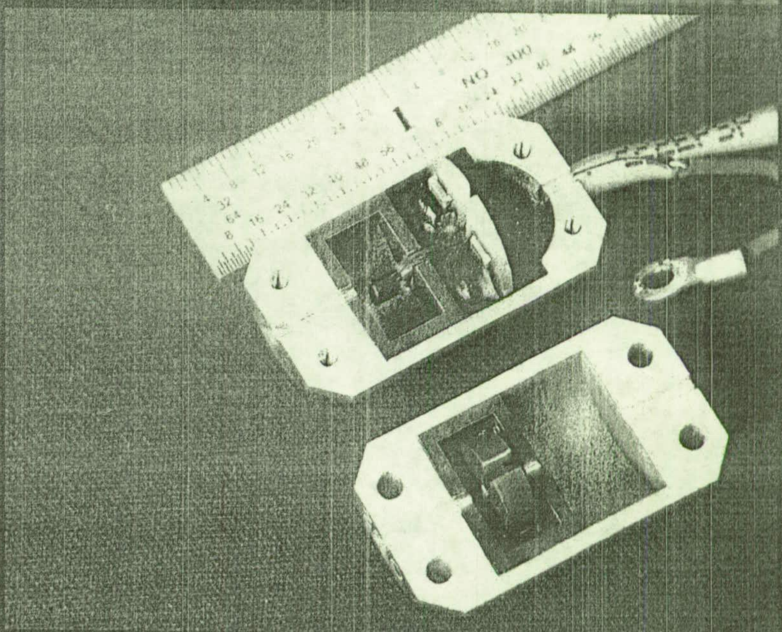
Objective

Develop non-invasive sensor, with embedded process-knowledge capability to detect and ultimately predict system's failures and/or degradation before they happen (failure trending and prediction)



Status

- Current signature sensor prototype (sensor assembly, analog, digital and power modules) was designed, fabricated, and tested.
- Smart software algorithms to detect failures and/or degradation under different external conditions were developed and tested.
- Patent application was filed and licensing of this technology has been granted to Schaffer for commercialization purposes



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Advanced Data Acquisition System

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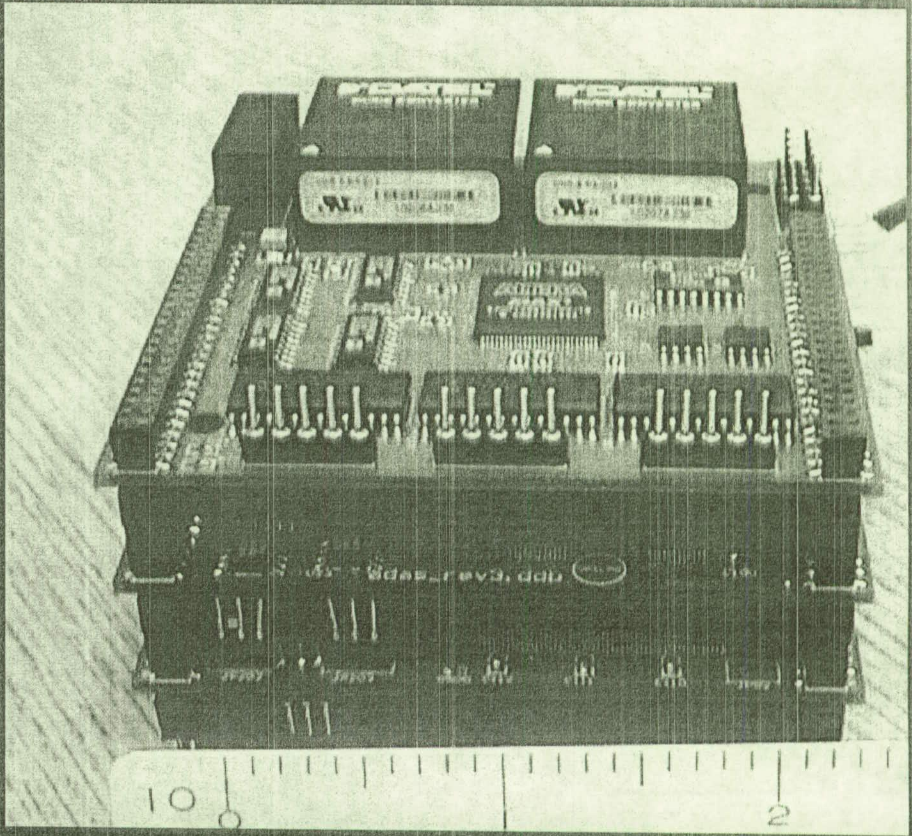

Objective

Develop a data acquisition system that incorporates self-health checks, self-calibrating, self-healing capabilities, and allow for greater measurement reliability with minimum number of component redundancy. Additionally, size, weight and power requirements will be minimized.

Project Status

- Architecture was defined and baselined
- Prototypes were designed and fabricated
- System was tested at laboratory
- environment
- Embedded software was developed and tested
- 4-channel generic system was demonstrated
- U.S. patent # 6,462,684
- Commercialization and licensing rights were issued to Circuit Avenue Netrepreneurs, LLC

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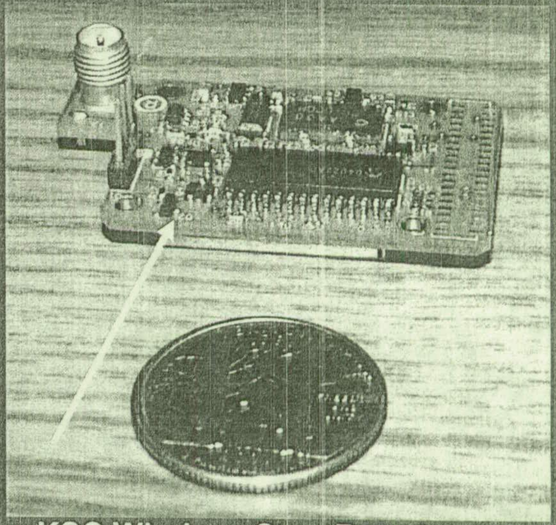
Wireless Sensors Network (*SensorsNet*)

Objective

Design embedded wireless data link capability in sensors and transducers.

Create a robust sensor network architecture design (capable of autonomous or "on-demand" reconfiguration)

Provide sensor network with embedded process-specific intelligence.



3rd Generation KSC Wireless Core Board

Status

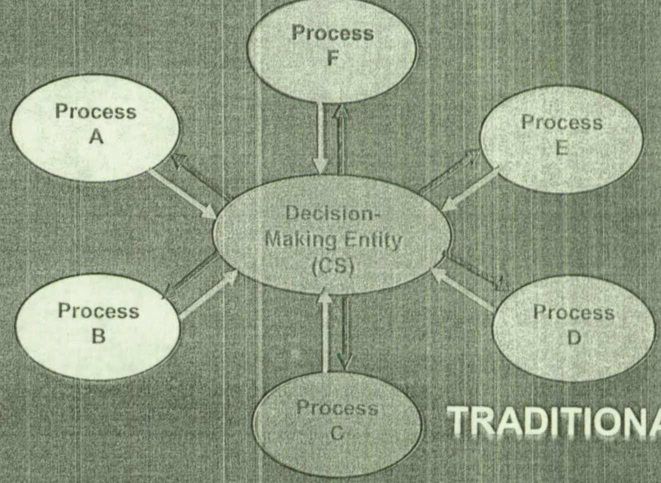
- Generic 433MHz and 918 MHz RF Core Module, Power Management Module, and Sensor Interface Module have been designed, fabricated and tested.
- Smart software algorithms to overcome RF path problems (communication drop out) have been designed and tested. Smart power management algorithms to optimize battery life have been designed and tested.
- Limited process-specific embedded knowledge in sensors has been demonstrated in the laboratory (information vs. raw data transmission).

Embedded Process Knowledge (*SensorsNet*)

Objective

Design intelligent sensor network with embedded process-knowledge at the sensor level. De-centralize process decision making.

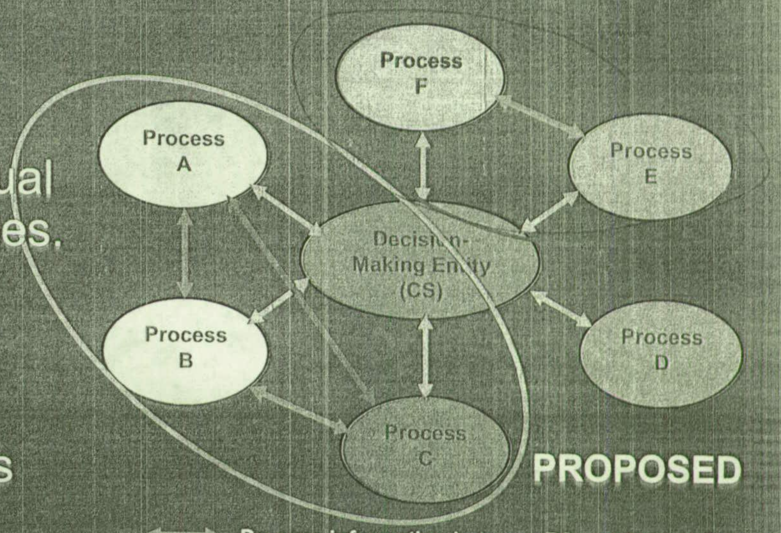
- **Design**
- Complex processes broken down into simpler, smaller processes. Relationship rules are created to link all processes to overall process.
- Share process knowledge/information among sensors and controlling equipment via wireless communication.
- Process health monitoring done through individual sensor performance and process knowledge rules.
- **Status**
- Process composed of 2 sub-processes and 6 measurements have been modeled and implemented. Testing is being performed at this time.



TRADITIONAL

Process raw data to Central Station

Command / decision from CS to Process

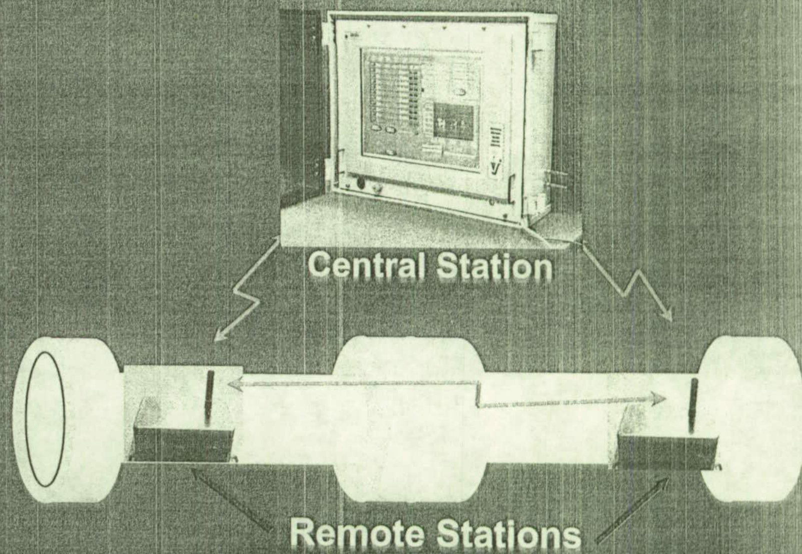


PROPOSED

Process information between RS and Central Station

Shared information between processes

Vacuum Jacketed (VJ) Line Wireless Sensor Network

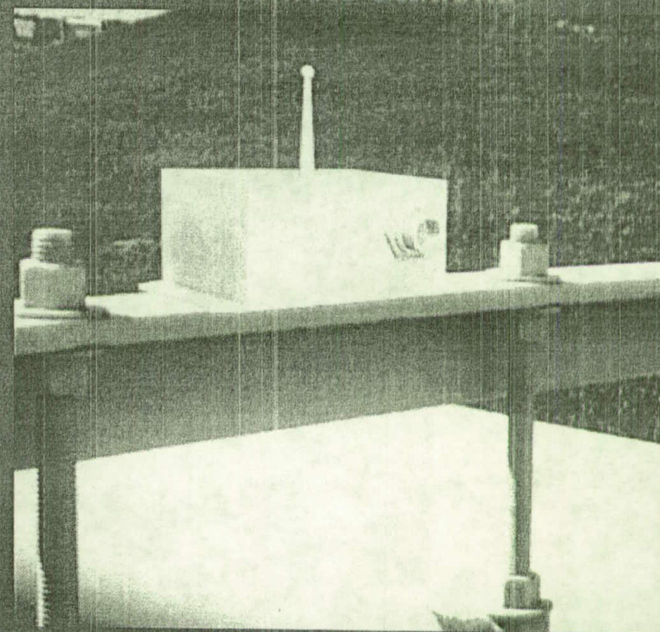


Objective

Provide the Launch Pads LH_2 and LO_x VJ lines with wireless sensors to autonomously monitor the conditions of the lines prior and during loading operations.

Status

- Operational requirements were developed
- Conceptual design was developed
- Hardware and software were based on the Wireless SensorNet development.
- A system (central station and 10 remote stations) was fabricated and tested.
- Supporting automated calibration station was designed, fabricated and tested.
- System was deployed at KSC Pad A at the present time.



Smart Sensor Networks

Smart Sensors Networks

- The arrangement of Smart Sensors in a network type configuration is the logical step to fully utilize the added capabilities of this approach. Communication between sensor and next higher assembly (system) is no longer constraint by a single wire connection. Smart Sensors can not only send data to the system but also to associated Smart Sensors in the network. Information from the system such as sensor/system configuration, sensor/system health, and process status can be easily share by sensors and next higher assemblies. Sharing of process states and transitions can also be performed. System does not degrade if connection between a sensor and the system is damaged; other communication paths are created and used.

- Although the primary means of connecting sensors in a network configuration has been established using wires (Ethernet, RS-485, etc), other configurations such as wireless have been successfully used. KSC has successfully demonstrated a Wireless Sensor Network approach at Space Shuttle launch pad A.

Smart Sensor Roles in ISHM

Role of Smart Sensors in Integrated System Health Management

- As previously discussed in this paper, Smart Sensors play a very important role in the Integrated System Health Management approach. Some of the roles discussed are:
  - Provide valid data (assess and qualify the validity of the data)
  - Provide processed data (data conversion and compensation)
  - Provide sensor health status (potential degradation and failures)
  - Provide embedded self-healing capabilities (self-calibration and self-reconfiguration)
  - Provide sensors networking capability (wired and wireless)
  - Provide higher reliability and longer calibration cycles
  - Provide automation and autonomy, reducing human intervention (reduced maintainability costs)
- These are some of the roles and characteristics that Smart Sensors bring to the ISHM architecture that enhances the operation, maintenance, reliability and autonomy of such system.

Summary

Summary/Conclusions

- The Integrated System Health Management (ISHM) approach presents a great opportunity for vast enhancements in reliability, cost reduction in vehicle and surface support equipment maintenance and operational costs, and a major leap on safety improvements for future space exploration missions. NASA has recognized the potential of intelligent health technologies and has supported development of specific subsystems and component technologies; ISHM is also an emergent core technology for many of the most advanced commercial and military avionic platforms. Ultimately, ISHM technologies will be the monitoring and control backbone in vehicles and ground support facilities for Moon and Mars exploration.

- The Integrated System Health Management (ISHM) architecture consists of traditional and smart sensors, software and computing that enable the monitoring and management of diverse systems. The ISHM effort supports the goals of *autonomy*, *modularity*, *re-configurability*, and *data-rich virtual presence* desired by the Exploration program. Accordingly, Smart Sensors are designed and developed following the same criteria. ISHM supports determination of nominal/off-nominal behavior so that other systems can take appropriate actions. Smart Sensors support that role by performing sensors' specific tasks, assigned by ISHM, to optimize the performance of this effort. The combination of Smart Sensors and ISHM technology presents the optimal approach to vehicle and surface support system health management.

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